An Integrated Modeling and Observational Study of Three-Dimensional Upper Ocean Boundary Layer Dynamics and Parameterizations

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Grants #'s: N00014-08-1-0447
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LONG-TERM GOALS

This study unites long-term efforts in understanding

- Mixed layer dynamics
- Processes that communicate atmospheric forcing to the ocean interior

with new long-term efforts to understand

- Submesoscale dynamics
- Mixed layer –eddy interactions

OBJECTIVES

Existing high resolution regional models typically resolve the mean vertical structure of the upper ocean boundary layer. Physically-based parameterizations of vertical fluxes make it possible to account for subgrid mixing at length scales smaller than the layer depth, but no specialized parameterization is used to represent the dynamics of horizontal mixing below the O(1)*km* - O(10)*km* resolution scale. We aim to determine the physical limitations of subgrid parameterization on these scales. This project addresses the following questions:

- What physics govern horizontal and vertical mixing in the presence of horizontal variability on the 1-10 km scale?
- What is the relative importance of horizontal and vertical mixing in determining the structure of the boundary layer?
- What physics should be included to improve parameterizations?

APPROACH

An adaptive measurement program employed acoustically-tracked, neutrally buoyant Lagrangian floats and a towed, undulating profiler to investigate the relative importance of vertical and horizontal mixing in governing boundary layer structure in the presence of O(1 km) scale horizontal variability.

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **30 SEP 2008**	2. REPORT TYPE	3. DATES COVERED
4. TITLE AND SUBTITLE **An Integrated Modeling And Observational Study Of Three-Dimensional Upper Ocean Boundary Layer Dynamics And Parameterizations**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Laboratory,1013 NE 40th St.,Seattle,WA,98105-6698**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
Existing high resolution regional models typically resolve the mean vertical structure of the upper ocean boundary layer. Physically-based parameterizations of vertical fluxes make it possible to account for subgrid mixing at length scales smaller than the layer depth, but no specialized parameterization is used to represent the dynamics of horizontal mixing below the O(1)km - O(10)km resolution scale.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Remotely sensed sea surface temperature and ocean color, combined with rapid, high-resolution towed surveys and model results guide float deployments to key locations within fronts. Synoptic, high-resolution surveys followed Lagrangian float drifts to characterize three-dimensional variability within the span of a model grid points. Acoustic tracking allowed towed surveys to follow floats and geolocated all observational assets for later analysis. Measurements characterized boundary layer turbulence and facilitated detailed separation of vertical and horizontal processes. All of this work is cooperative between this grant and the AESOP grants of Craig Lee and Ramsey Harcourt at APL.

Quantitative one-to-one statistical comparisons between LES results and the float and survey observations will be made. This product will have direct application to assessing regional model subgrid parameterizations.

WORK COMPLETED

The field component of AESOP consisted of 2 cruises applying the above approach. The first took place from R/V Roger Revelle, 16 July – 8 August 2006 off the California coast and produced, most importantly, detailed measurements of the time evolution of an approximately 5 km square Lagranigan volume of ocean at an oceanic front subject to mixing from a downfront wind and restratification as this wind relaxed. Details are included in our 2007 report. Analysis has been primarily conducted by Ramsey Harcourt and is described in his annual report.

The second field component focused on the strong fronts and submesoscale features associated with the Kuroshio extension as described in more detail in our 2007 report. The third survey, focusing on a strong, nearly linear, sharp and zonally-oriented section of the Kuroshio front extending offshore from Japan proved to be the most interesting. The pre-deployment section revealed intense cyclonic relative vorticity and optical signals indicative of recent subduction in strong gradient region. Over a 7-day period, Triaxus repeatedly occupied cross-front sections following the drifting float, attempting to characterize a region marked by two outcropping isopycnals. We have focused our analysis during 2008 on this section.

We worked with Dr. Luc Raineville, paying for some of his available time using our PostDoc funds, to refine the analysis of the density and velocity structure of this front. The major analysis task was to combine the upward- and downward-looking ADCP's on the towed Triaxus with the ship's ADCP to estimate the oceanic velocity all the way to the surface. This was done using an adaption of software developed for processing ship-lowered, profiling ADCP data. An example is shown in Fig. 1.

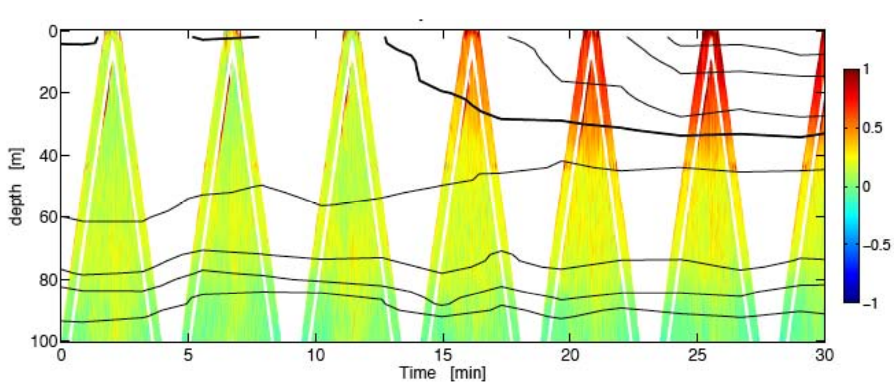

Fig. 1. Sample depth-time track of Triaxus (white) with ADCP velocities shown in color. Contours show the mapped velocity across the main front of the Kuroshio off Japan.

RESULTS

Our most dramatic new results show the cascade of processing resulting in enhanced mixing at the Kuroshio front. Fig. 2 shows the context of our measurements along the front formed by the confluence of the Kuroshio and Oyashio off Japan. The front is formed by strong mesoscale frontogenesis in this region.

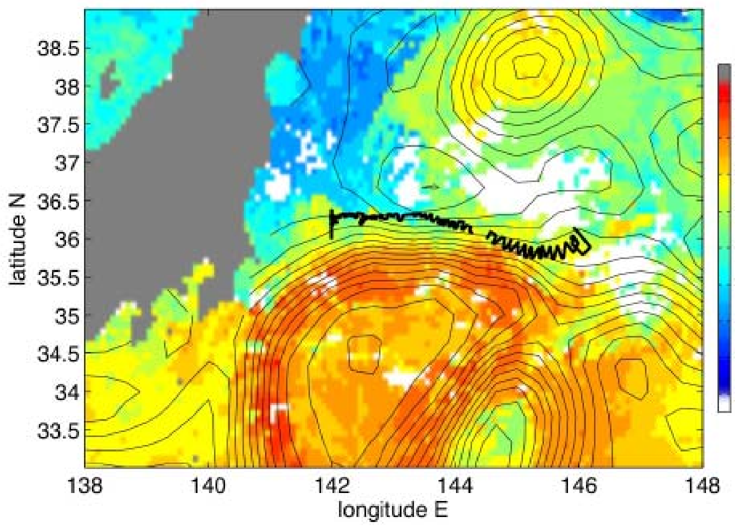

Fig. 2. Mesoscale structure of the Kuroshio off Japan during the AESOP measurements. SST (color) and SSH (black contours, 5-cm intervals) The ship track for Lee / DAsaros float and Triaxus survey of the sharpest front is shown in black. (SST from NASA Goddard Space Flight Center [MODIS on the Aqua satellite], and SSH from Aviso). The front is seen to be formed between two mesoscale eddies and the ship track positioned along the front.

Much of our analysis has focused at the end of the period of frontogenesis during which the front was only a few hundred meters across. The Lagrangian float deployed at this 'Sharpest front' found a vertical turbulent vertical kinetic energy much larger than has been found at similar wind speeds for other Lagrangian floats in the upper ocean boundary layer. During this time the stratification is stable and the buoyancy flux is upward so that normal upright convection is not occurring. Thus the boundary layer is being driven by the frontal gradients and not the atmosphere. The dissipation in this boundary layer, about 10^{-6} W kg^{-1}, therefore represents a loss of energy from the front and thus from the large-scale circulation that has formed it.

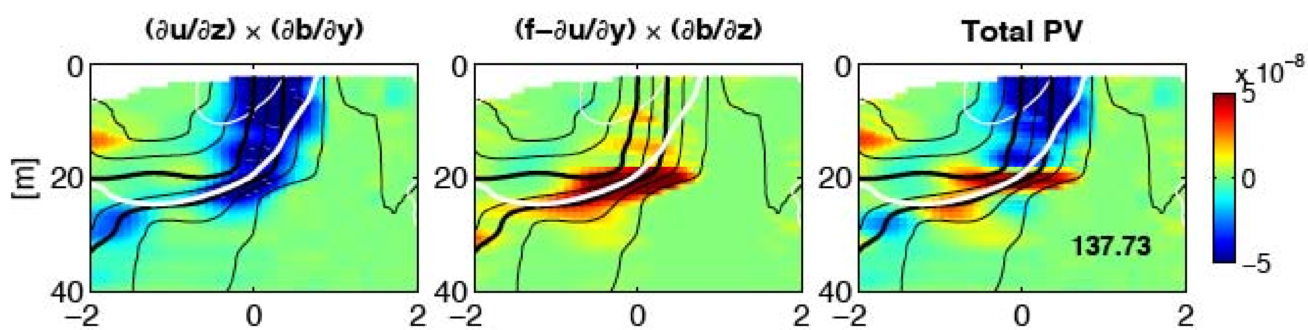

Fig. 3. Velocity (white contours) and density (black contours) structure across the 'Sharpest front' during the time of excess energy dissipation combine to make the Ertel potential vorticity negative in the mixed layer. The negative baroclinic terms (left) are partially compensated by the positive vertical terms (right).

A potential dynamical explanation for this excess mixing is found by examining the structure of Ertel potential vorticity at the front during this time. As shown in Fig. 3, the Ertel potential vorticity is highly negative at the front, mostly due to the baroclinic shear. This suggests that the excess mixing is due to symmetric instabilities, occurring only for negative PV, clearly drawing their energy from the larger scale flow and supporting the hypothesis that the excess boundary layer dissipation represents a loss from the general circulation.

This front appears to be the site of enhanced lateral mixing. The frontal width increases after the time of ‘sharpest front’, despite an overall confluence in this region. The rate of increase is several times faster than the typical spreading rate of drifter clusters in the open ocean. This, combined with the very much larger gradients, suggests unusually large horizontal fluxes due to mixing in this region.

IMPACT/APPLICATION

The observations of direct energy input from the general circulation into upper ocean boundary layer dissipation potentially unite previously separated studies of the mesoscale/submesoscale energy cascade and the upper ocean boundary layer. This work has generated considerable interest among mesoscale modelers. We hope that our continued interaction with this community will advance our understanding of these processes.

TRANSITIONS

None.

RELATED PROJECTS

SeaSoar and Doppler Sonar Spatial Survey of Internal Tide Generation and Mixing, Shaun Johnston and Daniel Rudnick.

REFERENCES

None.

PUBLICATIONS

None.